Mechanical Energy & Power Systems Laboratory

UNIVERSITY OF MINNESOTA

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Design and Modeling of Anchoring Segments of Burrowing Hydraulic Soft Robots

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Problem

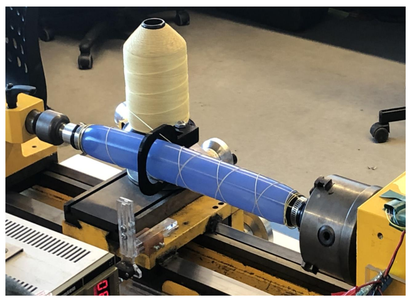
Many of today's utilities, such as water and telecommunication, use excavation and underground tunneling to institute these services. Current methods of installation and repair, primarily trench excavation and directional boring, come with drawbacks including:

- Large Equipment Necessary
- Environmentally Destructive
- Hazardous Conditions
- Manual Operation Required
- Limited Steering Capabilities
- High Costs

Design and Manufacturing

Axial Strain-Limiting Fitting Inserts

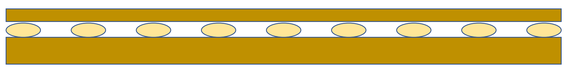
Anchoring Segment Barbed Hose Fitting with Strain-Limiting Insert and Threaded Rod



Lathe to Wrap Aramid Fibers on Pressurized Elastomer

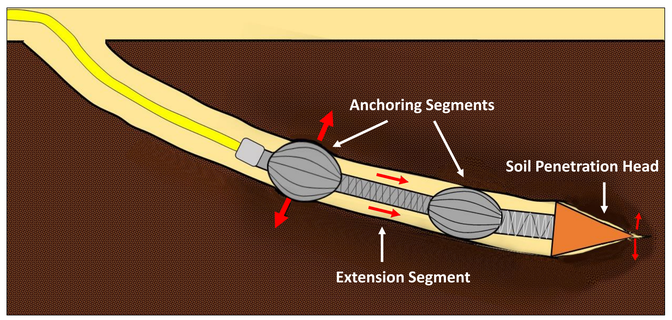
Custom Elastomer Manufacturing Assembly

Outer Polyurethane Layer Coating Fixture and Drying Rack

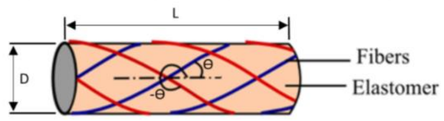


Cross-Section of Outside Layer Design Prototype 2 – Custom Base Elastomer Tube, Wrapped Aramid Fibers, Outer Protective Polyurethane Sandwich Layer

Concept and Impact



Potential Design of Multi-Segment Hydraulic Burrowing Robot



McKibben Actuator: An elastomer tube wrapped with equal and opposite fiber angles that will tend towards 54.7 degrees when pressurized.

The overall goal of this research is to develop the ability to model and control compliant, multi-segment robots using fiber reinforced elastomeric enclosures implemented through power-dense hydraulic systems. Applications of this efficient, high-force burrowing include:

- Underground wire and pipe installation and repair
- Exploration for natural resources
- Anchoring of off shore vessels
- Navigation through debris in natural disasters

This specific research focuses on the initial design of the anchoring segment and characterizing its anchoring force.

Anchoring Segment Model

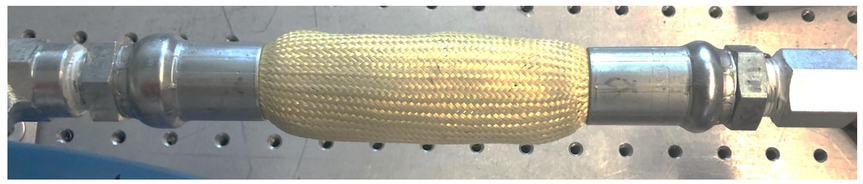
$$F_{\text{Anchoring}} = 2\pi r_t u_t l_{eff}\left(P - \frac{E\,t}{r_o r_t}(r_t - r_o)\right)$$

where

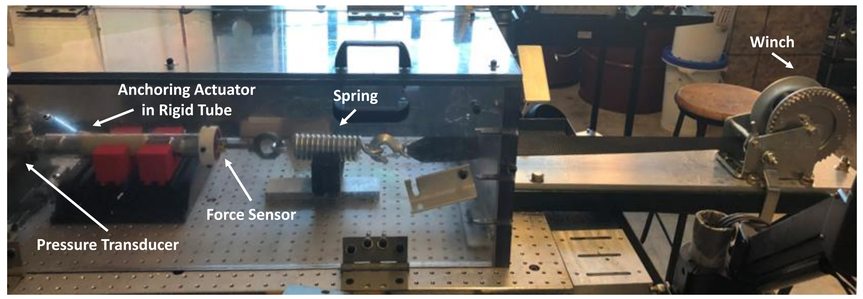
$$t = r_t - \sqrt{r_t^2 - t_k(2r_o - t_k)}$$

$F_{Anchoring} = anchoring\ force$
$u_t = coefficient\ of\ friction$
$l_{eff} = length\ of\ actuator\ in\ contact\ with\ wall$
$P = input\ fluid\ pressure$
$E = elastomer\ modulus\ of\ elasticity$
$r_t = expansion\ radius$
$t = expanded\ elastomer\ wall\ thickness$
$r_o = initial\ elastomer\ outside\ radius$
$t_k = initial\ elastomer\ wall\ thickness$

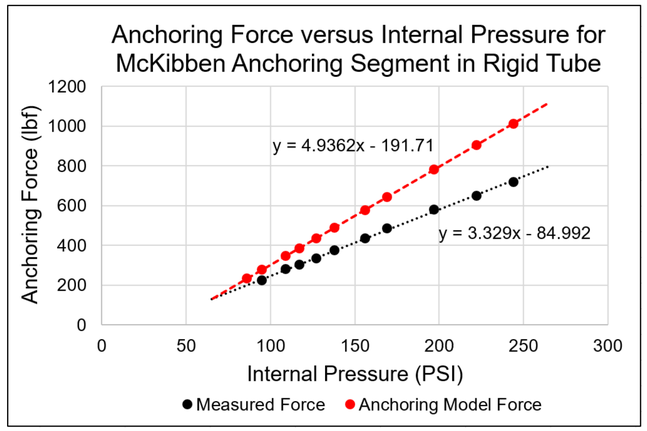
Testing and Results



McKibben Anchoring Segment Prototype 1 with Aramid Fiber Sleeve (Tested Model)



Testing Apparatus: A hydraulic circuit with a pressure transducer was used to measure the pressure within the anchoring segment. Anchoring force was determined by the winch force required to make the tube slip forward off the pressurized segment.



r_t=0.75 in
l_{eff}=4.19 in
u_t=.25
t=0.0769 in
(t_k=0.125 in)
E=758
r_o=0.5 in

The observable error in slope can likely be attributed to error in friction testing. The polycarbonate tube coefficient of friction was estimated using slope testing with a flat plate expected to be slightly rougher than the tube.

Future Research

- Finalize custom manufacturing
- Soil tube testing and modeling
- Optimize anchoring segment geometry
- Interface anchoring and extending segments